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## THIRD QUARTERLY REPORT

## RESEARCH AND DEVELOPMENT

## IN

## CdS PHOTOVOLTAIC FILM CELLS

By

T. A. Griffin, D. J. Krus, J. C. Schaefer

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

November 19, 1964 to February 19, 1965

CONTRACT NAS 3 4177

# THE HARSHAW CHEMICAL CO.

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Contract NAS 3-4177


Technical Management
NASA Lewis Research Center
Cleveland, Ohio
Space Power Systems Division
Clifford Swartz




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Crystal-Solid State Division
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# FOREWORD

This report was prepared by the Crystal-Solid State Division of the Harshaw Chemical Company. The work has been sponsored by the Space Power Systems Procurement Section of the NASA Lewis Research Center with Dr. A. E. Potter acting as Technical Advisor and Mr. Clifford Swartz acting as Project Manager.

Dr. J. McKenzie is the Technical Director of the Solid State Laboratory of the Harshaw Chemical Company. Project direction has been provided by Mr. J. C. Schaefer with Mr. T. A. Griffin as Project Supervisor and Principal Investigator. The following Harshaw personnel have contributed to this program: D. J. Krus, W. W. Baldauf, C. A. Marano and R. Rautenstrauch.

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# SUMMARY

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    Development of the CdS solar cell has continued toward the goal of improved cell life under thermal cycling tests, improved collection efficiency, and improved cell fabrication techniques.

    Efforts to improve the properties of the electroplated collector grid of the CdS thin film solar cell by means of procedural changes were continued. The large power losses of 50 to 75% encountered in the initial work have been reduced to less than 10%.

    Non-uniformities in the barrier layer have been found and have been photographed.

    Minor success has been achieved in forming a sintered CdS layer displaying a photovoltaic effect.

    A new laminator has been installed providing an even heat distribution and a large saving in time and convenience.

*Author*

RESEARCH AND DEVELOPMENT

IN

CdS PHOTOVOLTIAC FILM CELLS

INTRODUCTION

This report covers the second quarter of work on contract NAS 3-4177 which is a follow-on contract to NAS 3-2493. The present work places emphasis on making the film cell more uniform and reliable under launch and space conditions. The major objectives are to fabricate light weight, flexible, uniformly high efficient, low cost cells capable of operating in space for long periods of time.

This program is being implemented by a performance in-house test program at NASA's Lewis Laboratory. The results of tests such as ultra-violet exposure, electron and proton bombardment, and thermal cycling in high vacuum will be used to modify cell materials and construction in order to find those combinations that are most compatible with prolonged operation under space conditions.

During the first quarter the CdS thin film cells had been improved in power to weight ratio to about 40 watts per pound for 3" x 3" cells. This represents a significant increase over the 25 watts per pound reported on the previous contract.

Electroplated collector grids initially provided low efficiency cells. A constant improvement toward the higher value has been noted during this quarter. Cells of this type construction promise to reduce the cost by elimination of the costly gold electroformed mesh. The new cell packaging design has withstood hundreds of thermal cycles conducted in a vacuum chamber. The temperature cycles were conducted between +65°C and -70°C.

The procedure for applying the electroplated collector grid has a deleterious effect on the cell in proportion to the total plating time. Plating conditions have been continually altered to provide shorter deposition time which has resulted improvement of cell output. A simplified method for application of the photoresist method has been tested and found to be satisfactory.

The barrier surface has been photographed and found to have areas of discontinuity.

# ELECTROPLATED GRIDS

In recent Quarterly Reports a procedure for afixing a metallic gold grid by electrodeposition was reported. This procedure has been significant in increasing the lifetime of the CdS solar cell under thermal cycling. Applying such a grid, however, caused a large loss in conversion efficiency. Plating solutions and procedures compatible with the barrier layer have been energetically pursued to circumvent the crippling loss of cell power. Much progress has been made in this area.

Several procedural steps must be followed to obtain satisfactory results. These steps are reported below.

## 1. Photoresist Process

The first step is the application of a negative-photoresist layer over the barrier surface. The method requires exposing the resist-coated cell to light through a photographic mask which is a positive of the grid. Spraying the cell with developer, alcohol, and air, causes a photoresist mask to form on the cell. (That resist which is not exposed is removed by the developer.) After plating, the remaining resist (that which has been exposed) must be removed. The prescribed method for removal requires scrubbing the surface with a developer-soaked tissue and rinsing with alcohol. The above steps are repeated until removal is accomplished. This abrasive action may loosen or dislodge parts of the grid or the barrier. Several disadvantages are readily apparent.

A new positive-working photoresist was investigated which has been found to provide higher resolution, requires less heat during processing, lower frequency of pinholes, and can be more easily removed. To remove this resist mask after plating, the cell is briefly dipped in one of many organic solvents. Thus, resist removal requires no abrasion and only brief contact of the cell with foreign solutions.

A study involving twenty-four $1\frac{1}{2}$" x $1\frac{1}{2}$" sample cells was made to compare the performance of cells fabricated by the two photoresist procedures. Twelve cells were masked with negative-working photoresist and plated in the gold solution using the fifteen minute plating as described below. (See Gold Plating Process.) Twelve cells were also masked with positive-working photoresist and were plated in the same manner. All twenty-four cells were laminated. Comparison of physical appearance of the grid and IV characteristics of the cells before and after plating rendered both processes equal. Because of the ease of operation, the positive-working resist was adopted as standard.

## 2. Gold Plating Process

Results of thermal cycling tests indicate that electrodeposited grids adhere to the barrier more tenaciously than pressure-contacted electroformed mesh. Development of a grid of this type will render lamination

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unnecessary for affixing the current collector grids to the barrier. However, most metal plating solutions are waterbased, and the gold baths are cyanide solutions. Water and cyanides attack the barrier. Attempts to find a suitable non-aqueous electrolyte have been negative. Efforts are now directed toward developing a non-injurious plating technique using standard acid solutions.

Initially a plating time of 2 hours was required to note any current collecting ability. The long plating time caused severe degradation of the cells. An increase in plating current density to 1 ma/cm$^2$ and in temperature to 49°C made it possible to reduce the plating time to 45 minutes. A large reduction in the plating time at 49°C from 45 to 15 minutes has been effected by plating initially at a low current density of 1 ma/cm$^2$ for 5 minutes and then at a higher current density of 5 ma/cm$^2$ for 10 minutes. This method enables the use of a relatively high current density and an increase in the thickness of the gold deposit from 2.0 to 2.5 microns. Cells with power losses of 10% or less have resulted. It is possible that a linear increase of current density from a low value up to 5 ma/cm$^2$ may result in further improvement.

It has been found that a cell lowered into the plating solution with no voltage applied, becomes coated with gold, probably due to a chemical replacement reaction. Since the commercial gold plating solution is a proprietary formula, the specific reaction can only be speculated. Such replacement reactions have been previously noted as damaging to the barrier. In order to eliminate the possibility of such electroless or immersion plating, cathodic protection is provided by applying the voltage to the cell prior to immersion.

Solution filtering has also been found to be of importance in preventing cell degradation during electroplating. After a few cells have been plated, a yellow powder of unknown chemical composition appears suspended in the solution, making the solution appear cloudy. This material can be removed between platings by filtration. Gravity filtration requires about two hours. Pressure filtration is now employed between platings which requires considerably less time but does not meet the continuous filtration recommednation made in the solution operating specifications. A pump which combines continuous filtration with agitation is being investigated. A sample of the yellow precipitate will be analyzed to determine its chemical composition.

The gold plating parameters determined for the electroplated barrier cells appears to be also optimum for the chemiplated-barrier cells. Further, the chemiplated-barrier cells show little degradation when a fifteen minute plating time is used. In fact, a 3 in. x 3 in. cell with initially 440 ma $I_{sc}$ (in the pressure test unit), after grid electroplating gave 550 ma $I_{sc}$ (3.5% efficient).

There is some evidence that unheated, chemiplated-barrier cells do not degrade as rapidly in the presence of water vapor as heated cells. For this reason unheated, chemiplated-barrier cells were grid electroplated and then heated to maximum efficiency. In general, the open circuit voltages were low (.38 volts). However, there is some doubt as to

whether representative samples were obtained because of the low efficiency of the standard from the same 6 in. x 6 in. substrate. Cells with unheated, extra-thick barriers also showed a similar effect: low open circuit voltages (.20 volts). More experiments will be conducted in this area.

A high speed gold plating solution obtained from a commercial supplier has been investigated and found to be unsuitable for solar cell grid electroplating. Low open circuit voltages invariably resulted. Other plating solutions remain to be investigated. One is a high-speed gold plating solution, another is a neutral gold alloy plating solution, while a third one is a pre-plate or strike solution. A commercially available, neutral, cleaning solution primarily intended for cleaning copper printed circuits prior to plating was investigated. Improved contact and better adherence of electrodeposited gold was expected. Results of these tests show that, although the open circuit voltage remained about the same after gold electroplating, the short circuit current decreased to about one half of its original value.

Prior work on pressure test results has indicated that a 25 lpi grid network could be used instead of the present 70 lines per inch grid without loss of efficiency. With the 25 lpi grid more active cell area would be obtained. A test of eight 3 in. x 3 in. cells demonstrated that, using the present technology, 25 lpi electroplated grids are not sufficient to collect the carriers without a loss in efficiency.

3. Bus Bars

With an auxiliary anode configuration, it was possible to increase the bus bar thickness to five microns. However, it was discovered that when cells are electroplated without the bus bar network, the degradation is less. A non-deliterious method of bus bar plating is being sought.

A peripheral bus bar configuration is being investigated and compared with the "extended-H" network now employed. Theoretical considerations show that for a fixed bus bar network surface area and thickness, the square design should be more efficient. Preliminary investigations have shown that the two configurations are comparable. More work is planned in this area.

BARRIER UNIFORMITY

In the second quarterly report it was mentioned that some nonuniformities were found in the barrier layer. Some cells with low short circuit currents displayed a sprinkling of clear spots apparently devoid of a barrier. These spots were discovered by means of a microscope with polarized light directed toward the sample at normal incidence. Photographs have been made of the electroplated barrier showing the voids or holes in the barrier. These areas have been found to be as large as twenty microns across. Figure 1 illustrates one of these voids, right of center, at a magnification of 750X without a filter. Figure 2 is the same area viewed under red light, while Figure 3 utilized green light. These colored filters emphasize the missing barrier area on black and white panchromatic film. Under white light this vacant area looked red-orange indicating CdS, while the surrounding area appeared blue-gray.
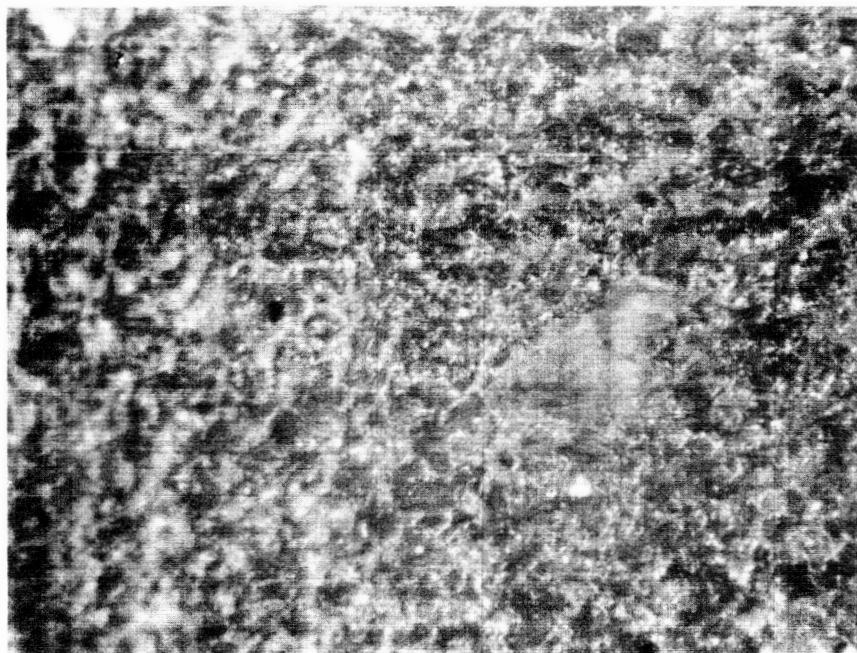
Figure 1.   Barrier Layer Under Polarized Light with No Filter
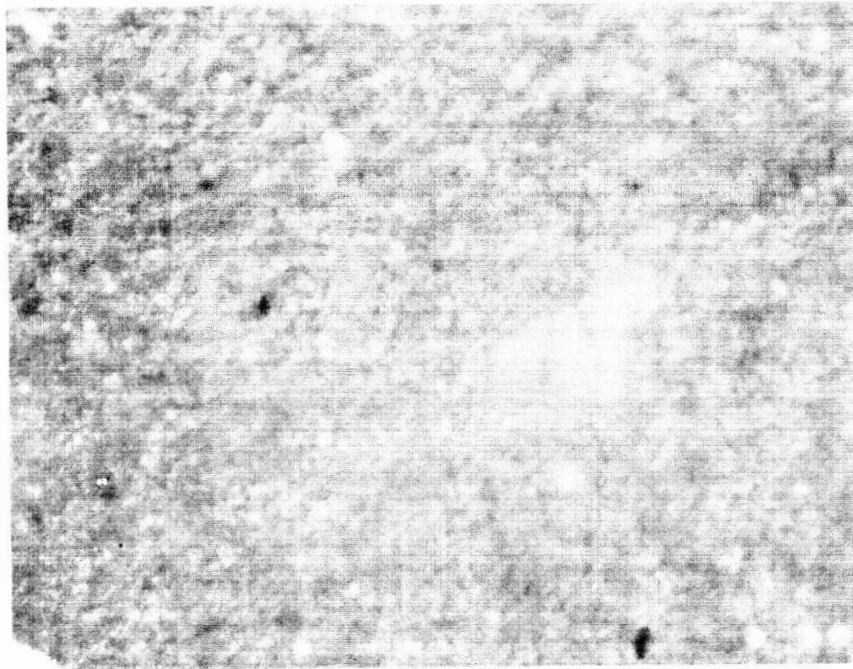
Figure 2. Barrier Layer Under Polarized Light and
Filter Passing Red Light
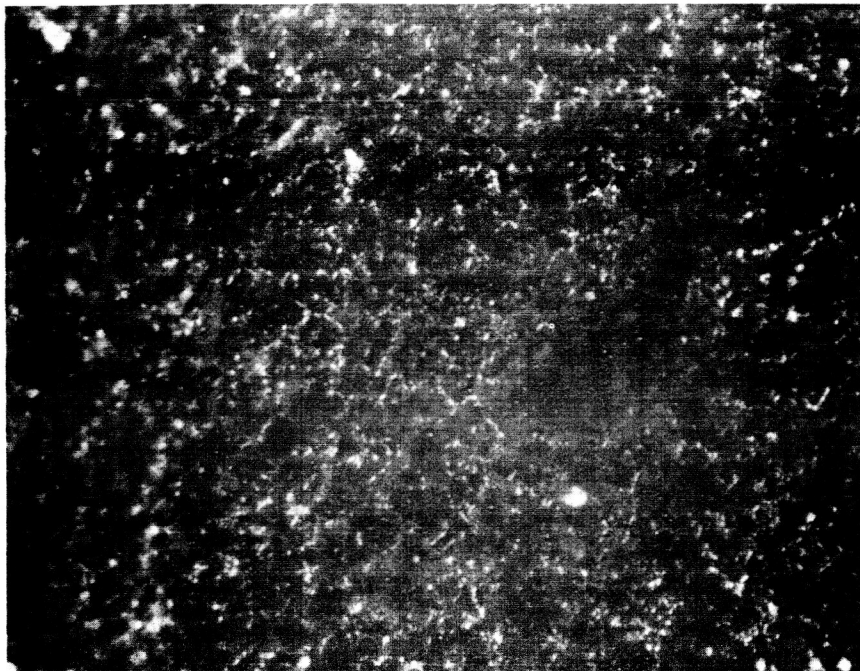
Figure 3.   Barrier Layer Under Polarized Light and
            Filter Passing Green Light

## TABLE 1

### HALL DATA ON BARRIER LAYER

| Sample | Treatment | Resistivity (ohm-cm) | Mobility ($cm^2$/v-sec) | Carriers ($c_i^{-3}$) |
|--------|-----------|----------------------|-------------------------|-----------------------|
| 1 | Lapped (unheated) | $5.62 \times 10^{-3}$ | 3.94 | $2.81 \times 10^{20}$ |
|   | Lapped (heated) | $4.16 \times 10^{-3}$ | 4.45 | $3.38 \times 10^{20}$ |
| 2 | $\frac{1}{2}$ Lapped $\frac{1}{2}$ Etched (unheated) | $5.97 \times 10^{-3}$ | 6.13 | $1.7 \times 10^{20}$ |
|   | $\frac{1}{2}$ Lapped $\frac{1}{2}$ Etched (heated) | $3.5 \times 10^{-3}$ | 10.6 | $1.68 \times 10^{20}$ |
| 3 | Etched (unheated | $9.07 \times 10^{-3}$ | 2.53 | $2.72 \times 10^{20}$ |
|   | Etched (heated) | $5.12 \times 10^{-3}$ | 3.61 | $3.38 \times 10^{20}$ |
| 4 | Etched (unheated) | $1.46 \times 10^{-2}$ | 3.43 | $1.25 \times 10^{20}$ |
|   | Etched (heated) | $3.71 \times 10^{-3}$ | 4.99 | $3.38 \times 10^{20}$ |

To develop a concept of the uniformity and stability of the chemi-plated barrier layer the following tests were conducted.

A copper sulfide layer was formed by chemiplating CdS single crys-tals having resistivities ranging from $10^4$ ohm-cm in the light, to great-er than $10^9$ ohm-cm in the dark. Such values should prevent the CdS from having an effect on the hall measurements made on the barrier layer. The barriers were put on lapped crystals, etched crystals, and crystal sur-faces that were one-half lapped and one-half etched.

All of the copper sulfide layers were measured and found to be p-type. The layer thicknesses were estimated to be about 2 microns. This estima-tion is an upper limit for the thickness.

After the film properties were measured the contacts were removed and the films were heated in vacuum for 12 minutes at $200^\circ$C. After heat-ing, the samples were fitted with new contacts and the properties of the film were measured again. Table 1 shows the results of the measurements before and after heating.

From this data it is evident that the copper sulfide film is rather insensitive to the condition of the surface it is placed on, and is not affected by being continuous to the high resistivity CdS. A temperature of $200^\circ$C does not affect the results.

SINTERED CdS FILMS

The purpose of this study was to develop a CdS film with photovoltaic properties from a suspension of CdS applied to a metallic substrate with subsequent sintering in an inert atmosphere. Substrates used for the study were cleaned using a standard wash and etch procedure and were stored in methyl alcohol to inhibit contamination until needed. The substrates were sprayed with a suspension of CdS in $H_2O$. $CdCl_2 \cdot 2\frac{1}{2}H_2O$ was also dis-solved in the water to aid in maintaining the suspension. The substrates were maintained at $100^\circ$C while spraying the suspension. The resulting films were sintered in an argon atmosphere. Presumably, this heat treat-ment volatilizes the $CdCl_2$ leaving a CdS film. The films found free of cracks and flaking were chemiplated.

Variables investigated were 1) substrates, (molybdenum and tin-coated stainless steel; 2) spraying technique, (time of each spray: 2 sec.; interval between sprays: 30 seconds; number of sprays: 24), 3) suspension concentration, ($\frac{1}{2}$ part to 5 parts $CdCl_2$ to 10 parts CdS) and 4) suspension composition, (Gafac dispersant additive; methyl alco-hol instead of $H_2O$). The results of 23 runs (53 substrates) are present-ed in Table II. Films made initially were mud-cracked and coarse textured. Indium probes showed that these films did not make ohmic contact to the substrate. Films numbered 10 thru 15, 17, 19 and 21 were barrier chemi-plated. Number 12 exhibited a slight photovoltaic effect; the other cells were not rectifiers and showed no photoeffect. An attempt to obtain better contact to the substrate was made by using two mil tincoated stainless steel.

However, the film flaked and cracked on these substrates.  Cells made from films 26 and 27 showed no photovoltaic effect.

Attention was again turned to using molybdenum substrates, while varying the concentration of $CdCl_2 \cdot 2\frac{1}{2}H_2O$.  First efforts with 1 part $CdCl_2$ to 2 parts CdS led to films which cracked and flaked when sprayed onto the substrate.  A concentration of 1 part $CdCl_2$ to 5 parts CdS was finally used. Cells were made from films numbered 38, 40, 45 and 59.  Film numbered 38, 45, and 49 gave photovoltaic effects with #38 having the greatest output: 0.26 volts, Voc; 9.8 ma, $I_{sc}$; 0.23% efficient; area: $3cm^2$.  Surprisingly, an x-ray diffraction pattern of the surface of film #41 (produced under the same conditions as film #38) showed no preferred orientation.

The results of this study show that a CdS film formed by sintering of sprayed material produces a photovoltaic effect.  The characteristics of such films at present are 1) no preferred orientation, 2) poor ohmic contact to the substrate, and 3) contains many pinholes and cracks.

## TABLE II

### SINTERED CDS FILMS

| Run No. | Cell Nos. | Suspension Mix* | Substrate Mat'l and Size | Sintering Temperature (°C) | Sintering Time (min) | Film Appearance |
|---|---|---|---|---|---|---|
| 1 | 1,2 | A | Pyrex 1" x 3" | 600 | 30 | Brown in center, yellow edges, mud cracked |
| 1A | 1,2 | | | 600 | 30 | No improvement after additional heat |
| 2,3 | 3-7 | A | Molybdenum 3/4"x1½" | 700 | 30 | Dark brown, mud cracked |
| 4 | 8,9 | A | Molybdenum 3/4"x1" | 650 | 30 | Less mud cracks |
| 5 | 10,11 | A | Molybdenum 3/4"x1" | 600 | 30 | Same as Run 4 |
| +6 | 12,13 | A | Molybdenum 3/4"x1" | 700 | 30 | Same as Run 4 |
| 7 | 14,15 | A | Molybdenum 3/4"x1" | 600 | 30 | Same as Run 4 |
| 8 | 16,17 | A | Molybdenum 3/4"x1" | 500 | 30 | Reddish-yellow, coarse texture |
| 9 | 18,19 | A | Molybdenum 3/4"x1" | 300 600 | 15 30 | No improvement |
| 10,11 | 20-23 | B | Molybdenum 3/4"x1" | 600 | 30 | Smoother |
| 12 | 24,25 | C | Tin-coated SS 3/4"x1" | 300 700 | 15 30 | Flaked film, dark yellow |
| 13,14 | 26-29 | C | Tin-Coated SS 3/4"x1" | 700 | 30 | Same as Run 12 |
| 15 | 30,31 | C | Tin-Coated SS 3/4"x1" | 800 | 30 | Same as Run 12 |
| 16 | 32,33 | D | Molybdenum 3/4"x1" | No Sinter | | Smoother films but chipped on spraying |
| 17,18 | 34-37 | D | Molybdenum 3/4"x1" | No Sinter | | Same as 16 |
| +19,20 | 38-41 | E | Molybdenum 3/4"x1" | 700 | 30 | Fairly smooth |

| Run No. | Cell Nos. | Suspension Mix* | Substrate Mat'l and Size | Sintering Temperature (°C) | Sintering Time (min) | Film Appearance |
|---|---|---|---|---|---|---|
| +21 | 42-45 | E | Molybdenum 3/4"x1" | 650 | 30 | Fairly Smooth but dark spots |
| +22,23 | 46-53 | E | Molybdenum 3/4"x1" | 650 | 40 | Same as 21 |

+  Cell from run showed photovoltaic effect

*  Suspension  A:  5 gms. CdS, $\frac{1}{2}$ gms. $CdCl_2 \cdot 2\frac{1}{2}H_2O$, 50 mls.$H_2O$
                    B:  Gafac dispersing agent added to A
                    C:  $CH_3oH$ instead of $H_2O$
                    D:  10 gms. CdS, 5 gms. $CdCl_2 \cdot 2\frac{1}{2}H_2O$, 50 mls.$H_2O$
                    E:  10 gms. CdS, 2 gms. $CdCl_2 \cdot 2\frac{1}{2}H_2O$, 50 mls.$H_2O$

# EVAPORATED FILM PROPERTIES

It was shown in the earlier section on barrier uniformity that a copper sulfide layer was relatively stable when in contact with high resistivity CdS. However, many cells fabricated in the normal way, were not stable. The cause of this instability was not evident and may not be due to the copper sulfide, but may be caused by non-uniformities in the CdS film. Several standard runs were checked for uniformity by measuring the bulk electrical properties. Below are three recent films and their properties:

| Film | Resistivity (ohm-cm) | Mobility ($cm^2$/v-sec) | Carriers ($cm^{-3}$) |
|------|----------------------|-------------------------|----------------------|
| S161A | 7.35 | 3.02 | $2.51 \times 10^{17}$ |
| S165A | 13.2 | 1.74 | $2.72 \times 10^{17}$ |
| S185A | 59 | 0.38 | $2.79 \times 10^{17}$ |

The resistivities reported are lower than usual. Previous films fell in the 100 to 1000 ohm-cm range. This change could not be related to any changes in the evaporation parameters or materials. Further tests are being run in which the evaporation conditions are being widely varied. A closer control on resistivity was indicated. Control of carrier concentration by doping rather than by cadmium excess was deemed necessary. Therefore CdS powder was doped with indium for use as the evaporant. The calculated range was $10^{19}$ $cm^{-3}$. The data obtained from the films show that the doping range was attained in the films.

| Film | Resistivity (ohm-cm) | Mobility ($cm^2$/v-sec) | Carriers ($cm^{-3}$) |
|------|----------------------|-------------------------|----------------------|
| S169A | $5.8 \times 10^{-3}$ | 80.9 | $1.34 \times 10^{19}$ |
| S173A | $2.2 \times 10^{-2}$ | 30.2 | $9.53 \times 10^{18}$ |

These films did not produce the expected gain in efficiency or in stability. However, they did demonstrate that the film properties can be controlled by an added dopant rather than relying on the cadmium excess.

More experiments are being conducted in order to establish the combination of electrical properties necessary to the CdS films to produce the best photovoltaic cells. It is possible that the highest efficiency and most stable cells will require not only definite bulk properties, but also a layer of different properties near the junction. This could explain the variation experienced in junction formation times, in efficiency, and in stability for cells produced from CdS films with similar bulk electrical properties.

# ALTERNATE SUBSTRATE MATERIALS

## 1. Conductive Paper

Films were successfully evaporated on conductive paper. These CdS films had a close even texture. Very little problem was experienced with thermal expansion match. There were, however, two problem areas. The first was the insufficient conductivity of the paper. To overcome this the paper was coated with a layer of silver. This was applied by spraying and by evaporation. The second problem was the embrittlement of the paper during the barrier formation process. This made the handling after plating rather difficult.

Some cells were made with silver interface layers of sprayed silver. All of these cells shorted during test. This was due to the uneven silver which caused the CdS to be uneven, and therefore caused localized shorts through the thin areas.

A cell 2 cm$^2$ was made on a paper coated with several hundred angstroms of evaporated silver. This cell was 1.3% efficient. It was very brittle after barrier formation. The feasibility of using such paper was demonstrated. However, because of the necessity of using an interface conductor on the paper and with the advantages of the chemical milling process it does not now offer any advantage over the molybdenum substrate. It is possible that in a production process the paper could be used as a supporting substrate and then discarded in the final cell packaging.

## 2. Invar

Some evaporations were made on invar at high substrate temperatures. The higher temperatures seem to eliminate the yellow powder interface between the CdS and the molybdenum. Sufficient cells will be fabricated to determine the merits of further investigation.

## IMPULSE LAMINATOR

The laminating procedure previously used required that the cell package be placed in platens and heated in a laminating press for more than one-half hour. The time factor and effects of uneven heating dictated the need for an improved technique or a new procedure. Recently The Harshaw Chemical Company installed an impulse type laminator capable of completing an encapsulation cycle in a few minutes. Instead of utilizing heated platens the heat is supplied directly to the cell package through a thin metal diaphram heater. This unit is faster and is able to handle much larger arrays. The most important fact is the short heating and cooling cycle necessary to seal the plastic films without drastically altering their physical characteristics.

The sealer has been made operational. By testing various gauges of aluminum foil (1 mil, 2 mil, 3 mil and 4 mil) it was found that the 1 mil aluminum was the most effective heater element for the sealer. The optimum lamination cycle was then found to be 45 sec with the 1 mil foil heater element. With the heavier foils the lamination cycle is reduced to about 30 sec., but wrinkles develop in the plastic film as a result of the rapid buildup of heat. The longer 45 sec. cycle permits a gradual increase in temperature resulting in a less shrinkage due to orientation of the thermoplastic film. Cells have been laminated on this unit ranging in size from 3" x 3" operative cells to a 16-3" x 3" cell square foot array (mechanical sample).

Comparative tests were made on the two lamination procedures. The test consisted of taking a 3" x 3" cell, No. S103 which had an original efficiency of 2.3%, and cutting it into four $1\frac{1}{2}$" x $1\frac{1}{2}$" cells designated A, B, C, and D. Cells A and B and the plastic to be used were placed in a Vac Oven for 24 hours at 160°F and 29" Hg vacuum. Cells C and D were placed in a desiccator for 24 hours prior to lamination. Cells A and C were then laminated in the impulse sealer while cells B and D were laminated by the longer method of heated platens. The cells were tested electrically before and after lamination. The data obtained indicates comparable results.

| Cell No. | Type of Lamination | Cell Efficiency Before Lamination | Cell Efficiency After Lamination |
|---|---|---|---|
| S103-A | Impulse Sealed | 2.45% | 2.72% |
| S103-C | Impulse Sealed | 2.25% | 2.41% |
| S103-B | Heated Platens | 2.08% | 2.38% |
| A103-D | Heated Platens | 2.33% | 2.69% |

During this quarter twenty-six 3" x 3" operative cells were laminated outside of the pilot line. Fifteen of these 3" x 3" cells were sealed using the new impulse seal method of lamination while the remaining eleven were laminated by the heated platens method. The average efficiency of the cells by both methods of lamination was 2.8% efficient. The highest efficiency obtained from a laminated cell was 3.9% efficient. About fifteen cells ranging in sizes less than 3" x 3" were also laminated for special test purposes. The only array laminated was a 4 - 3" x 3" cell array connected in series with the following electrical characteristics:

| Voc | Isc | Power | Area | Efficiency | Wt. | Watts per Pound |
|---|---|---|---|---|---|---|
| 1.8v | 475ma | 518mw | 178cm$^2$ | 2.91% | 9.5 Grams | 35 |

# PILOT LINE

During this quarter the pilot line which was previously supported jointly by NASA and the Air Force was switched to a line solely supported by NASA.

The chemiplated barrier cells have displayed much higher efficiencies than the electroplated barriers prior to this quarter. Therefore it was decided to switch the pilot line to chemiplated barriers.

As expected the average efficiency did rise. However trouble is being experienced in the final steps of cell production. Many cells found satisfactory when tested prior to grid plating or lamination have decayed while stored in desiccated atmospheres. Previous experience has shown that placement in a high vacuum results in recovery of efficiency.

One hundred cells were fabricated on the pilot line during this quarter. These cells were all tested on the pressure test unit. The average efficiency was 3.2%. The highest efficiency was 4.5%.

The 10% drop in the peak efficiency is due to the changes that were incorporated in the chemiplated barrier process to make it more amenable to pilot line operation. A portion of this may be due to changes in the CdS film properties. Rapid production of barrier layers may have been instituted too soon.

## WORK PLANNED FOR THE NEXT QUARTER

1. Work will be continued on the electroplated grid to shorten plating time and to increase the density and thickness of the deposited metal.

2. Films of various doping levels will be made and fabricated into cells.

3. Evaporation of CdS films on Invar at high substrate temperatures will be continued.

4. Cells and arrays required for delivery by end of contract will be fabricated.

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